Using DEA to measure the seaports efficiency of China and five member countries from ASEAN

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ABSTRACT

In this paper, the efficiency and performance is evaluated for ports of China and five member countries(Singapore, Philippines, Brunei-Darussalam, Indonesia, Myanmar) from Association of Southeast Asian Nations (ASEAN).The aim of our study is to compare seaports situated on the maritime trade road between China and five member countries from ASEAN. Data was collected for 9 years (1999-2007) and a non-parametric linear programming method, DEA (Data Envelopment Analysis) is applied. This method is used to measure the efficiencies of ports in different countries, is constructed with three input factors (numbers of cranes, numbers of berths, quay length) and two output factors (Throughput, vessel calls).The goal of our study to estimate the performance level of the ports under considerations. This paper discusses the efficiency analysis, and gives specific direction for the inefficient ports to improve their operation efficiency possibly. This will help in proposing solutions for better performance and developing plans.

Key word -China and five number countries form ASEAN Seaports; Data Envelopment Analysis (DEA); evaluation; Seaports Efficiency.

1. INTRODUCTION

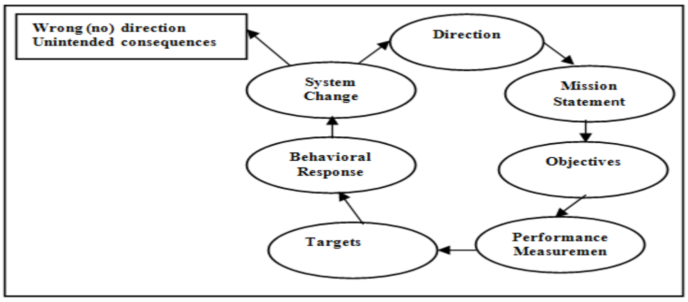
The globalization of the world economy has led to an increasingly important role for transportation. In particular, container transportation plays a key role in the process, largely because of the numerous technical and economic advantages it possesses over traditional methods of transportation. Standing at the crucial interface of sea and inland transportation, the significance of the container port and its production capabilities cannot be ignored. Compared with traditional port operations, containerization has greatly improved port production performance because of two reasons. To reap economies of scale and of scope, liner shipping companies and container ports are respectively willing to deploy dedicated container ships and efficient container handling systems. In so doing, port productivity has been greatly enhanced. On the other hand, many container ports no longer enjoy the freedom yielded by a monopoly over the handling of cargoes from within their hinterland. They are not only concerned with inter-port competition, under the orthodox microeconomic framework, is believed to provide an incentive to improve port performance. Productive efficiency, therefore, is a survival condition in a competitive environment.

Under such a competitive environment, port performance measurement is not only a powerful management tool for port operators, but also constitutes a most important input for informing regional and national port planning and operations. Traditionally, the performance of ports has been variously evaluated by calculating cargo-handling productivity at berth (Bendall and Stent, 1987; Tabernacle, 1995; Ashar, 1997) by measuring a single factor productivity (De Monie,1987) or by comparing actual with optimum throughput over a specific time period (Talley,1998). In recent years, significant progress has been made in the measurement of efficiency in relation to productive activities. In particular, non-parametric frontier methods such as Data Envelopment Analysis (DEA) has been developed with applications across a wide range of sectors including transit services. A recent work by De Borger, Kerstens and Costa (2002) claims that frontier models have found their way into the transport sector, and studies on the productivity and efficiency of almost all transport modes are appearing. Marlow and Paixão (2002) advocate that DEA should be used for performance measurement of ports and its suitability has been examined by Wang, Cullinane and Song (2003).

Against this background, this paper aims to provide new information on efficiency estimation by applying the techniques of DEA to the terminal data set derived from the countries' leading container ports. The paper is structured as follows: section 2 investigates performance measurement in relation to port production. A brief overview of nonparametric efficiency measurement techniques, discussing the DEA models, is included in section 3. Operationalisation and the analysis of results are provided in sections 4 and 5 respectively. Finally, conclusions are drawn in section 6.

2. PORT PRODUCTION MEASUREMENT

Performance measurement plays an important role in the development of a company or any other form of organizational Decision Making Unit (DMU). Dyson (2000) claims that performance measurement plays an essential role in evaluating production because it can define not only the current state of the system but also its future, as shown in Figure1. Performance measurement helps move the system in the desired direction through the effect exerted by the behavioral responses towards these performance measures that exist within the system. Mis-specified performance measures, however, will cause unintended consequences with the system moving in the wrong direction.



Source: Dyson (2000, p. 5)

Figure 1: Performance Measures and Organizational Development

Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport. As such, it is possible that a port may provide sound service to vessel operators on the one hand and unsatisfactory service to cargo or inland transport operators on the other. Therefore, port performance cannot normally be assessed on the basis of a single value or measure. The multiple indicators of port performance can be found in the example of the Australian port industry (Talley, 1994). The indicators are selected from the perspective of the stevedore, the shipping line and the port authority (or port management). Evaluations are made by comparing indicator values for a given port over time as well as across ports for a given time period. The port performance indicators suggested by UNCTAD (1976), as shown in Table 1, underlie productivity and effectiveness measures and can be used as a reference point.

Table 1: Summary of performance indicators suggested by UNCTAD

Financial indicators	Operational indicators
Tonnage worked	Arrival late
Berth occupancy revenue per ton of cargo	Waiting time
Cargo handling revenue per ton of cargo	Service time
Labour expenditure	Turn-around time
Capital equipment expenditure per ton of cargo	Tonnage per ship
Contribution per ton of cargo	Fraction of time berthed ships worked
Total contribution	Number of gangs employed per ship per shift
	Tons per ship-hour in port
	Tons per ship hour at berth
	Tons per gang hours
	Fraction of time gangs idle

Source: UNCTAD (1976, pp.7-8)

Talley (1994) goes further by attempting to build a single performance indicator – the shadow price of variable port throughput per profit dollar - to evaluate the performance of a port. This overcomes the drawback of multiple indicators, i.e. that examining whether port performance has improved or deteriorated becomes difficult when changes in some indicators improve performance and changes in others affect it negatively. In an effort to more properly evaluate port performance, several methods have been suggested, such as the estimation of a port cost function (De Neufville and Tsunokawa, 1981) the estimation of the total factor productivity of a port (Kim and Sachish, 1986) and the establishment of a port performance and efficiency model using multiple regression analysis (Tongzon, 1995).

In recent years, DEA has occasionally been used to analyze port production. Compared with traditional approaches, DEA has the advantage that consideration can be given to multiple inputs and outputs. This accords with the characteristics of port production, so that there exists, therefore, the capability of providing an overall evaluation of port performance.

3. METHODOLOGIES

3.1 Model Selection

An efficient production frontier defines the relationship between inputs and outputs by depicting graphically the maximum output obtainable from the given inputs consumed. In so doing, it reflects the current status of technology available to an industry. Ignoring all the economic complexities associated with the particular or possible source, or cause, of inefficiency (such as technical (productive), allocative or scale efficiency), at its most fundamental level, a DMU is considered efficient if it operates on the efficient frontier. On the other hand, a DMU is regarded as basically inefficient (for whatever reason) if it operates beneath the efficient production frontier.

Data Envelopment Analysis (DEA) is one of the many available alternative techniques (categorized either as econometric or as mathematical programming) for estimating an approximation to the efficient frontier. This mathematical programming techniques allow the measurement of the relative distance that an individual DMU (data observation) lies away from this estimated frontier and, thereby, also yield measures (usually in index form) of the relative inefficiency of the individual DMU in question, as compared to what amounts to an industry 'best practice' output/input ratio.

In fact, DEA is the most important non-parametric techniques to measure the efficiency of DMUs with multiple outputs and inputs. First introduced in Charnes, Cooper and Rhodes (1978), DEA has been widely used because it can be applied in a diverse variety of situations and has also been the subject of a number of theoretical extensions that have increased its flexibility, ease of use and applicability (Allen *et al*, 1997). As the counterpart of DEA, first appeared in Deprins, Simar and Tulkens (1984) and according to Lovell and Vanden Eeckaut (1993) is gradually becoming more popular.

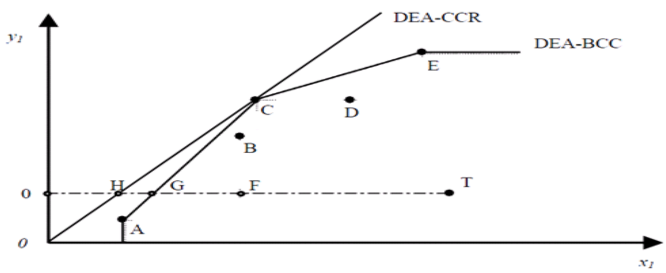


Figure 2: Non-parametric Deterministic Frontiers

DEA has its respective strengths and weaknesses (Lovell and Vanden Eeckaut, 1993). As such, a comparative study of this approach may provide greater insight into the intricacies of measuring production efficiency. Efforts in this respect include, *inter alia*, the efficiency of municipalities (Vanden Eeckaut *et al*, 1993) and the efficiency of retail banking, courts and urban transit (Tulkens, 1993).

DEA, as the deterministic non-parametric methods, assume no particular functional form for the boundary and ignore measurement error. Instead, the best practice technology is the boundary of a reconstructed production possibility set based upon directly enveloping the observations. These extremal methods use mathematical programming techniques to envelop the data (in a piecewise linear way) as tightly as possible, subject to certain production assumptions that are maintained within the mathematical programming context.

Convex non-parametric frontiers in the context of DEA allow for linear combinations of observed production units. According to this definition, all linear combinations of observations A and C are feasible in Figure 2.

Figure 2 illustrates the two most widely used DEA-models: The DEA-CCR (due to Charnes, Cooper and Rhodes, 1978) assumes constant returns to scale so that all observed production combinations can be scaled up or down proportionally. This constant return to scale DEA frontier is derived simply by the ray through the origin passing through point C. The DEA-BCC model (due to Banker, Charnes and Cooper, 1984) on the other hand, allows for variable returns to scale and is graphically represented by the piecewise linear convex frontier.

DEA-CCR and DEA-BCC models define different production possibility sets and efficiency results. As an example, the input-oriented efficiency of unit T in Figure 2 is given by the DEA-CCR model and 0G/0T by the DEA-BCC model.

3.2 Model Orientation

DEA models can be distinguished according to whether they are input- or output-oriented. One called input-oriented that aims at reducing the input amounts by as much as possible while keeping at least the present output levels, and the other, called output-oriented, maximizes output levels under at most the present input consumption.

Both orientations have their usefulness within the context of an application to the container port industry. The former is closely related to operational and managerial issues, whilst the latter is more related to port planning and strategies. A port is normally able to approximately predict its container throughput for the ensuing year at least. This is because a container port has a fairly stable customer base of shipping lines. Over the fairly short-term, container terminals should even be able to predict impending dramatic changes, such as Maersk-Sealand's decision in 2000 to move its regional hub from Singapore to the Port of Tanjung Pelepas in Malaysia. A container terminal can also attempt to predict its future throughput by studying historic data or regional economic developments. In that case, how to efficiently use the inputs is the key to saving costs in port production.

On the other hand, with rapid expansion of globalization and international trade, many container ports must frequently review their capacity in order to ensure that they can provide satisfactory services to port users and maintain their competitive edge. Sometimes, the need to build a new terminal or increase capacity is inevitable. However, before a port implements such a plan, it is of great importance for the port to know whether it has fully used its existing facilities and that input has been minimized given the output. From this perspective, the input-oriented model provides a more appropriate benchmark for the container industry. For the purposes of this study, it has been decided that input-oriented models should be chosen as the basis for the analysis. The fundamental reason for this choice is that since the main interest of the paper lies with informing policy-decisions.

3.3 Model Specification

There are two kinds of models used usually, one is DEA-CCR model, which is used to evaluate the overall efficiency (scale and technical efficiency) of the DMU, the other one is DEA-BCC, which is to evaluate the technical efficiency of the DMU only, the models for an input-oriented efficiency measurement problem are as follows.

Suppose there are n DMUs, with m input factors and S output factors; let j denote one of DMUs. The efficiency of the j^{th} DMU, with outputs Y_{ri} and (with r = 1,2,…,s) and inputs X_{ir} (with i=1,2,…,m), is calculated by the following DEA-CCR model

$$(a)\begin{cases} \min\theta \\ s.t\sum_{j=1}^{n}\theta X_{j0}-\lambda_j X_j \geq 0 \\ \sum_{j=1}^{n}\lambda_j Y_j \geq Y_{j0} \\ \lambda_j \geq 0,\ j=1,2,\ldots,n \end{cases}$$

λ_j is the coefficients associated with the selection of an efficient frontier point for the evaluation of DMU_{j0}

θ is the efficiency of DMU_{j0} respectively.

For the model (a), there are such rules

(l)If θ=1, then the j^{th} DMU is overall efficient, that means in the system that is formed by DMUs, the output Y_{j0}

has been optimum under the input X_{j0}

(2)If $\theta<1$, then the j^{th} DMU is inefficient, it is scale inefficient or technical inefficient, or scale and technical inefficient. That means in the system, the output can be maintained by decreasing the input X_{j0}

(3) Suppose

$$k=\sum_{j=1}^{n}\lambda_j$$

(a) If k=1, then the DMU will be operating at constant returns to scale;
(b)If k <1, then the DMU will be operating at increasing returns to scale;
(c)If k >1, then the DMU will be operating at decreasing returns to scale.

DEA-BCC model is to add the constraint

$$\sum_{j=1}^{n} e_j\lambda_j = 1$$

that is

$$(b)\begin{cases}\min \theta \\ s.t\sum_{j=1}^{n} \theta X_{j0} - \lambda_j X_j \geq 0 \\ \sum_{j=1}^{n} \lambda_j Y_j \geq Y_{j0} \\ \sum_{j=1}^{n} e_j\lambda_j = 1 \\ \lambda_j \geq 0,\ j=1,2,\ldots,n\end{cases}$$

e_j is a suitably dimensioned vector of unity values.

Rules (1) and (2) for model (a) is also suitable for model (b). It is shown that the overall efficiency, calculated from the DEA-CCR model, can be decomposed into the technical efficiency measured by DEA-BCC model and the scale efficiency. Indeed, the scale efficiency score of a DMU is the ratio of the overall efficiency to the technical efficiency, and using the DEA-BBC model can specify the major sources causing overall inefficiency.

4. OPERATIONALISTION

4.1 Definition of Variables

A thorough discussion of variable definition is provided in Cullinane, Song and Wang (2003), and can be summarized as follows. The input and output variables should reflect actual container port production as accurately as possible. To this end, a systematic investigation of container production is necessary. As far as container port production inputs are concerned, a container terminal depends crucially on the efficient use of labour, land and equipment. T he total quay length, the terminal area, the number of gantry cranes, the number of yard gantry cranes and the number of straddle carriers are the most suitable to be incorporated into the models as the input variables. In the light of the unavailability or unreliability of direct data, information on labour inputs is derived from a pre determined relationship to terminal facilities. On the other hand, container throughput is unquestionably the most important and widely accepted indicator of port or terminal output. Almost all the previous studies treat it as an output variable, because it closely relates to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Another consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a port.

4.2 Data Sources

Data were collected from various sources to test and run the model as formulated in the previous section. The data are concerned with two output measures (Throughputs, Vessel Calls), three input measures (Number of berths, Number of cranes, Quay lengths) of six countries (Philippines, Brunei Darussalam, Indonesia, Myanmar, Singapore, China). The six countries' seaports were selected and aggregated on the basis of industrial complex, population map, transportation network, province and metropolitan and special city size with the help of an expert's advice in transportation as follows with each region numbered with its name: Philippines seaports, Brunei seaports, Indonesia seaports, Myanmar seaports, Singapore seaports and China seaports.

Table-2: Input and output factor of ports

Country	Philippines	Brunei	Indonesia	Myanmar	Singapore	China
Number of cranes	18	10	60	20	140	3970
Number of berths	14	9	18	10	54	3659
Quay length(meter)	4914.5	350	600	400	1600	807102
Through put(million tons)	392.86	10.78	564.13	110.98	2078.24	33160
Vessel calls	89057	11252	506466	10119	1235068	11869200

Source: Ministry of Transport of P.R.C, Research in China, Brunei Darussalam website
Source: People Republic of China, China Port Industry report, 2006-2007 & 2008-2009

5. RESULTS OF THE EFFICIENCY ANALYSIS

In this section, the DEA linear programming model is validated using the data given in Section 3 to check whether or not the model represents the real situations in China and ASEAN-5. In this paper, we use MATLAB software to do the calculation (programs are at the rare of the paper), the results are in the table 3.

Table-3: Port Efficiency of CCR and BCC Model

Country No.	CCR		BCC	$\sum_{j=1}^{n}\lambda_j$	RTS	Scale score
	θ (Overall Efficiencies)	Reference	θ (Technical Efficiencies)			
c_1	1	c_1	1	1	Constant	1
c_2	0.1257	c_5	0.4482	0.0091	Increase	0.2805
c_3	1	c_3	1	1	Constant	1
c_4	0.3681	c_1, c_5	0.3738	0.0643	Increase	0.9848
c_5	1	c_5	1	1	Constant	1
c_6	0.8038	c_1, c_3, c_5, c_6	1	34.758	Decrease	0.8038
Average	0.7163		0.8037			0.8449

$c_1 = Philippines, c_2 = Brunei, c_3 = Indonesia, c_4 = Myanmar, c_5 = Singapore, c_6 = China$

5.1 Overall Efficiency Analysis

The CCR results, listed in Column 2 of Table 3, show that the ports of Philippines, Indonesia and Singapore performed the best ports than the other ports of countries when evaluated on the constant returns-to-scale assumption associated with this model, as evidenced by the fact that ports of Brunei and Myanmar were below the average and ports of China were above the average. Ports of Philippines, Indonesia and Singapore are the best performers. However, ports of Singapore are the best performers among the ports of 3 countries, and furthermore it is the ports of country most frequently referenced for evaluating inefficient ports of countries. It is used as a reference for all inefficient ports of countries and serves as the most influential referent, i.e., with the largest λ value. Ports of Singapore are the most efficient one in CCR measure. For confirmation, we might note that ports of Singapore are famous for its unique managerial strategies under the strong leadership of its owner.

5.2 Scale Efficiency and Technical Efficiency Analysis

The BCC scores provide efficiency evaluations using a local measure of scale, i.e. under variable returns-to-scale. In this model, ports of China are accorded efficient status in addition to the three CCR efficient ports of countries — which retain their previous efficient status. Ports of China's full efficiency with the BCC model is caused by its use of the smallest amount of inputs. Ports of Brunei and Myanmar are below average.

5.3 Scale Efficiency

The scale efficiency as defined by the ratio, CCR/BCC, exhibits large differences between the ports of countries. Ports of China and Brunei are below average whereas other ports of countries are above it. This may mean Ports of Philippines, Indonesia, Myanmar and Singapore are in an advantageous condition compared with those in the China and Brunei. But the ports of Brunei are the worst among the ports of 6 countries. Their overall inefficiencies (CCR) are mainly attributed to their inefficient operations or management.

Ports of countries with full efficiency in the CCR score are also efficient in the BCC model, the region where constant returns-to-scale prevails. Ports of Philippines, Indonesia and Singapore have this status. Ports of China and Myanmar show that they have a possibility to improve their efficiency by scaling up their activities. This observation leads us to hypothetically study the desirability of merging low ranked ports of China and Myanmar.

6. CONCLUSION

In this paper, DEA models are applied to evaluate the efficiency of performance of ports in different countries. Two DEA models (CCR model and BBC model) are used to evaluate the overall efficiency, technical efficiency, and scale efficiency of all ports of countries. Based on the results, the specific directions for the inefficient ports of countries to improve their operation efficiencies are discussed. In addition, the input and output factors for the performance of ports of countries are proposed, and successive period of one country can be taken as the DMUs to do the evaluation by DEA, which will help the owner to identify its improvement. Therefore, this study may provide useful information for the policy makers to implement ports performance better.

ACKNOWLEDGEMENT

This work was supported in part by Shanghai Science Commission Project (No. 09DZ2250400), Shanghai Science Commission International Cooperation Project (No. 09530708200), and Shanghai Municipal Science Commission Local University Capability Project (No. 08170511300), Shanghai Education Commission Leading Academic Discipline Project (No. J50604) and Shanghai Science Commission Project (No. 10692103500).

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